X-Ray Pulse Compression Using Deflecting Cavities - Studies at LBNL

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Acknowledgements

J. Byrd, J. Corlett and S. Zholents
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Jiaru Shi, H-B Chen and S-X Zheng
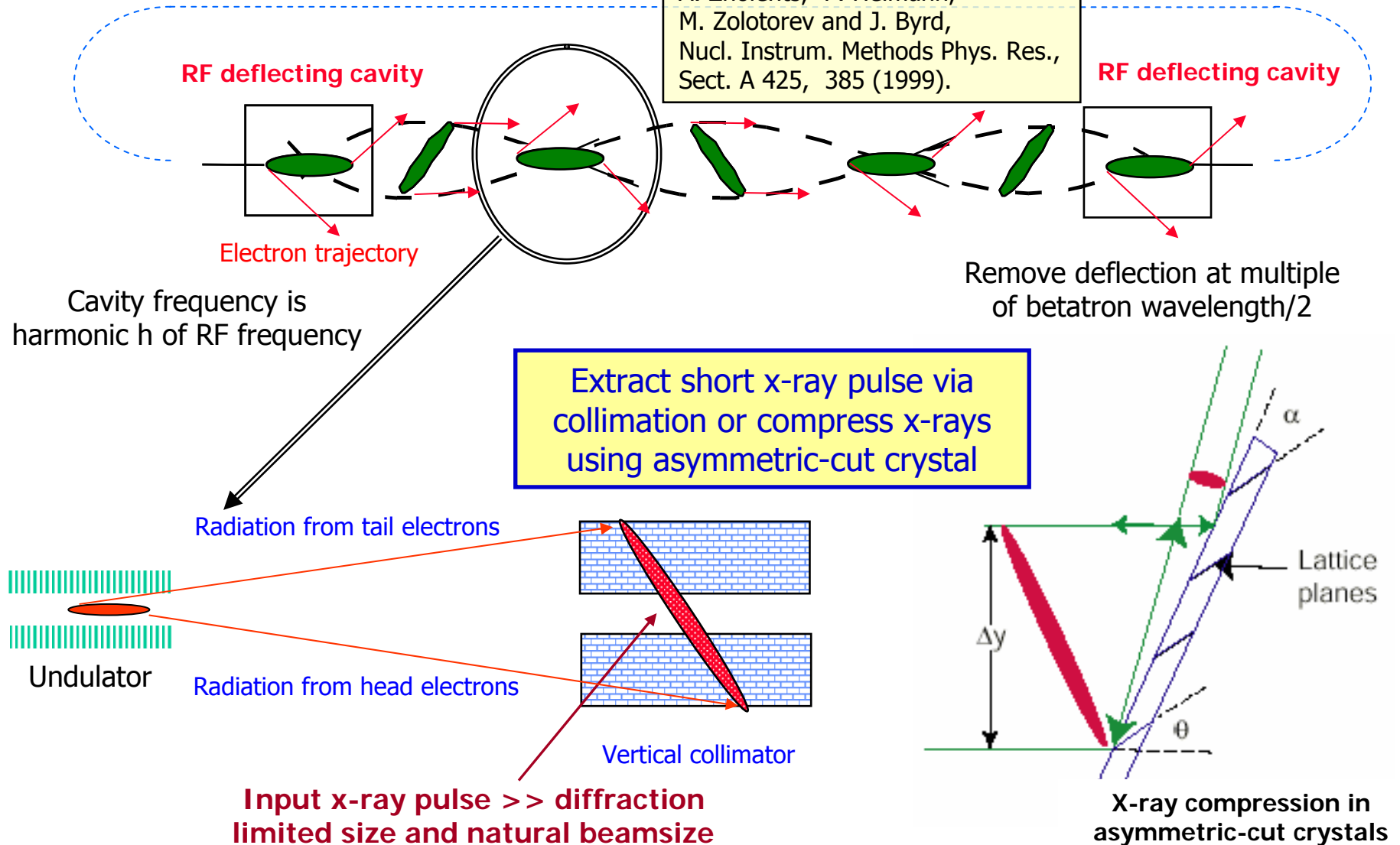**Tsinghua University, Beijing, China**

R. A. Rimmer
Jefferson National Accelerator Laboratory

K. Hosoyama
KEK, Japan

X-ray pulse compression via vertical chirp

A. Zholents, P. Heimann,
M. Zolotorev and J. Byrd,
Nucl. Instrum. Methods Phys. Res.,
Sect. A 425, 385 (1999).

RF deflecting cavity

RF deflecting cavity

Electron trajectory

Remove deflection at multiple
of betatron wavelength/2

Cavity frequency is
harmonic h of RF frequency

Extract short x-ray pulse via
collimation or compress x-rays
using asymmetric-cut crystal

Radiation from tail electrons

Radiation from head electrons

Undulator

Vertical collimator

**Input x-ray pulse >> diffraction
limited size and natural beamsize**

α

Lattice
planes

Δy

θ

**X-ray compression in
asymmetric-cut crystals**

Expected performance

$$\sigma_{t,xray} = \frac{E}{V\,h\,\omega_a}\sqrt{\sigma^2_{y',e} + \sigma^2_{y',rad}}$$

Deflecting voltage and frequency

Unchirped electron divergence

Photon beam divergence

- *V*h* gives shorter x-ray pulse limited by RF nonlinearity
- For existing electron bunch lengths, $f_{deflecting} < 3$ GHz
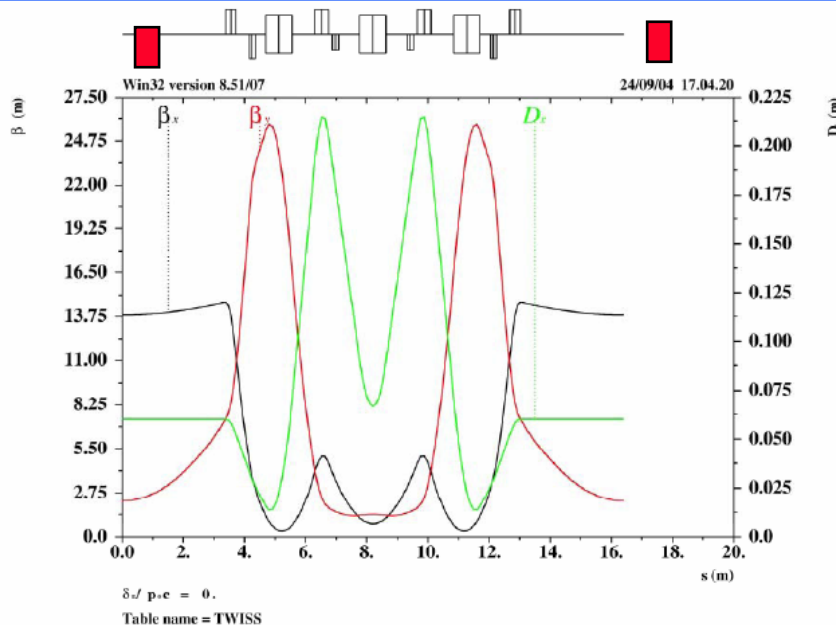- CW operation at desired voltages requires SC cavities

Table 1: Parameters of the picosecond source

Parameter	Value
RF deflecting cavity voltage	2 MV
RF deflecting cavity frequency	1.5 GHz
Vertical emittance	30 pm rad
FWHM electron bunch length	70 ps
FWHM Pulse length	0.7 ps
Vertical β-function at cavity	4 m
Vertical β-function at central bend source	1.6 m

D. Robin, et al. PAC05

LBNL R&D

- **X-Ray pulse compression using the deflecting cavity for LUX**
  - — **Studied 9-cell, 7-cell and 5-cell cavities at 1.3 and 3.9-GHz**
  - — **7-cell cavity at 3.9-GHz was proposed**
    - NC and SC cavity options of the deflecting cavity
    - Impedance simulations for LOM and HOM
    - Possible damping schemes of LOM and HOM
    - Impedance requirements for LUX (2-GeV, 40-μA beam current)
      - 8.5 MV RF deflecting voltage needed at 3.9-GHz for 2-ps bunch
- X-ray pulse compression using deflecting (crab) cavities to sub-pico-second bunches appears feasible for 3rd generation light sources
- Under intense study at Advanced Light Source (LBNL) and Advanced Photon Source (ANL)
- Issues under study:
  - — Optics, dynamic aperture, emittance growth
  - — RF amplitude and phase requirements
  - — X-ray pulse compression
  - — **LOM and HOM-damped SC deflecting cavities**
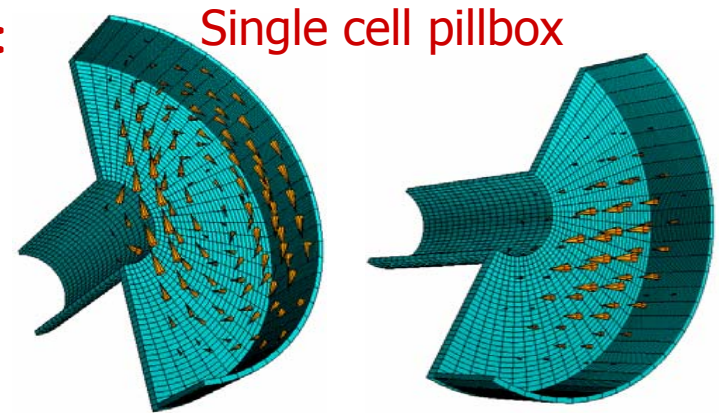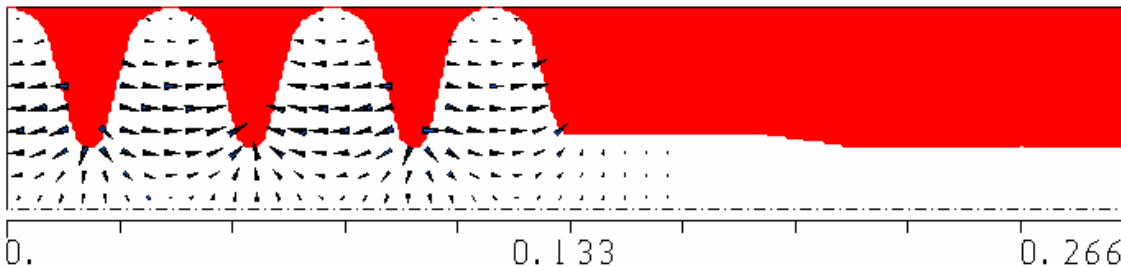- **Most of this work is relevant to crab crossing at LHC**

Deflecting Cavity Studies
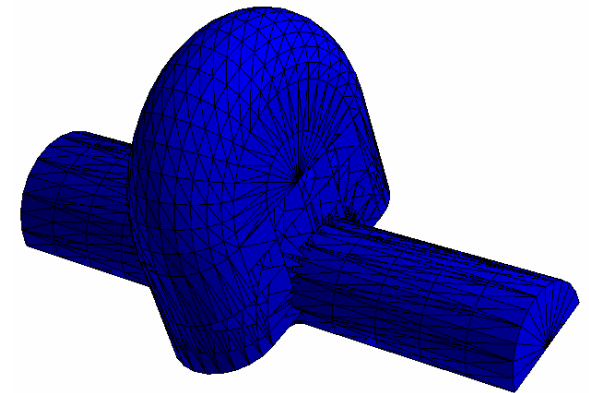
Shunt Impedance of the deflecting mode:

$$\left(\frac{R}{Q}\right)^* = \left(\frac{V_T^2}{P_W}\right)\frac{1}{Q} = \frac{|\int E_z(r=r_0)e^{jkz}dz|^2}{(kr_0)^2\omega U}$$

Single cell pillbox

What have we learned so far on the deflecting mode?

- Hybrid mode between TM and TE
- Magnetic and electric forces add up at π mode
- *(R/Q)* * ~ 50-60 Ω
- LOM and HOM + coupled LOM and HOM modes
- Degenerate mode

Squashed KEK-B cavity

Base on KEK-B crab cavity, Cornell and Fermilab SC multi-cell deflecting RF cavities for Kaon separation

Multi-Cell Deflecting Cavity

A 3-cell cold test cavity was built at Tsinghua University, Beijing

— Good agreements between CST Microwave Studio simulations and measurements in frequencies and field distributions

— (R/Q)* measurement

— More measurements will be carried out on LOM and HOM damping schemes later
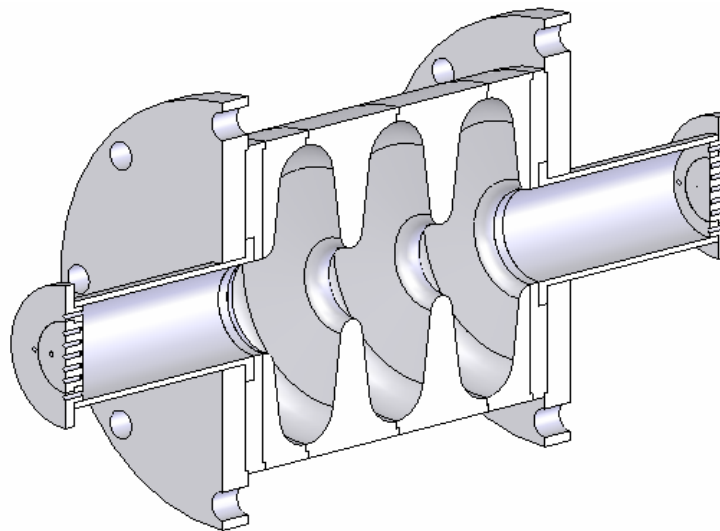

Al model of a 3-cell deflecting cavity at Tsinghua University and experiment setup for microwave measurements: frequency, (R/Q)*, LOM, HOM damping schemes and RF couplers

External Q calculations by MWS

Method has been benchmarked against measurements for a HOM damped cold test cavity at J-Lab

- SMW simulations in time domain
- Waveguide boundary conditions at ports
- Excite cavity from one RF (HOM) port
- Record and observe field (energy) decay as a function of time inside the cavity
- External Q is calculated from decay time

Excitation pulse

E-Field decay
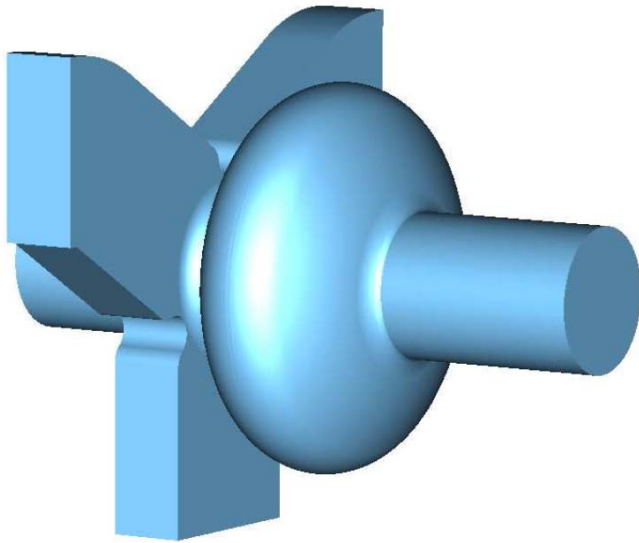
MWS model of J-Lab HOM damped SC cavity
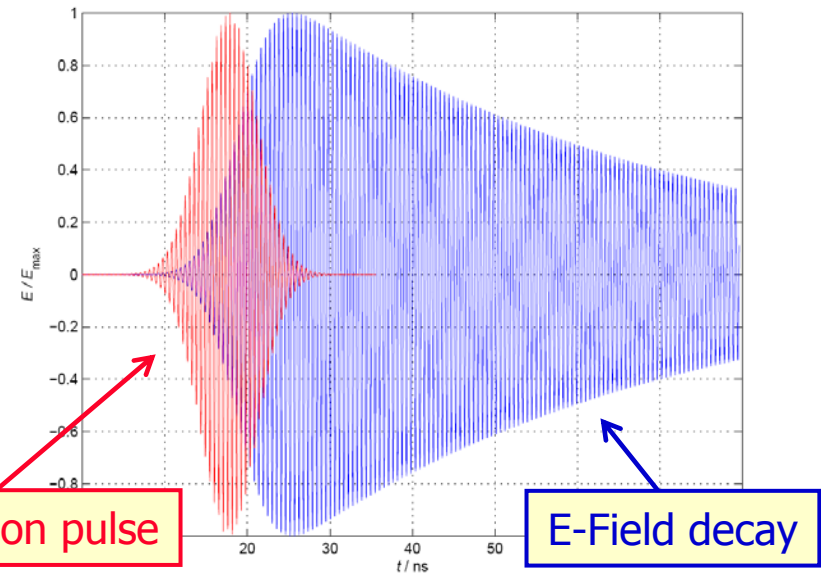
MS Calculated		Measured	
f/GHz	Q_{load}	f/GHz	Q_{load}
1.84727	276	1.848006	317
1.84764	264	1.848252	227
2.03046	719	2.029628	996
2.03055	746	2.030226	667
2.43190	2750	2.426183	2878

Single Cell Cavity Study

Coaxial damping of the monopole LOM modes were first studied for different beam pipe sizes (R)

- Coaxial insert damping is very effective
- Unwanted dipole mode & its frequency is pushed away by geometry (squashed in one plane: KEK scheme)
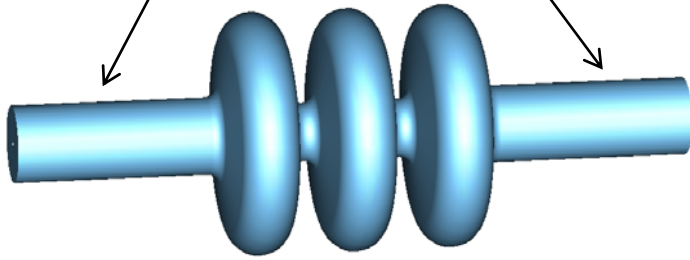
→ Muti-cell cavity may give better packing factor
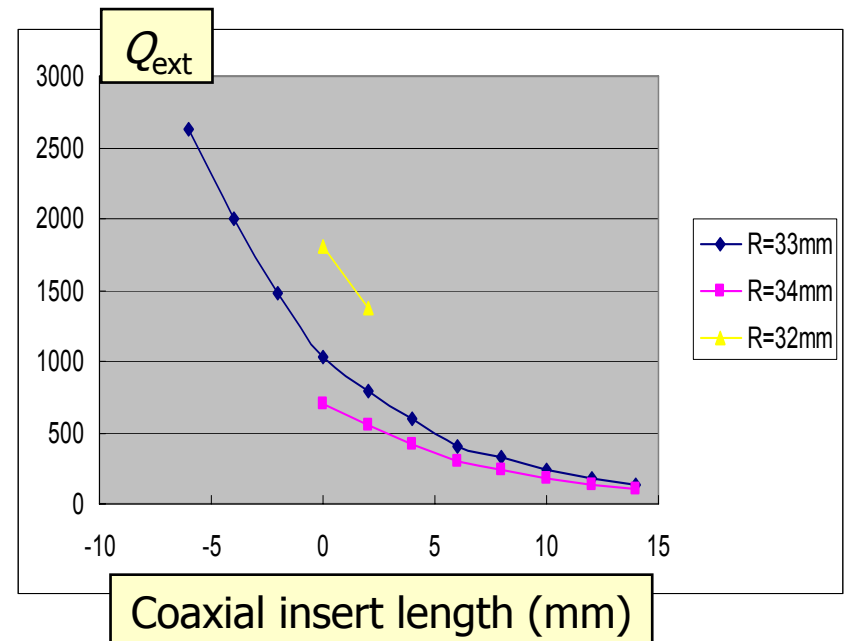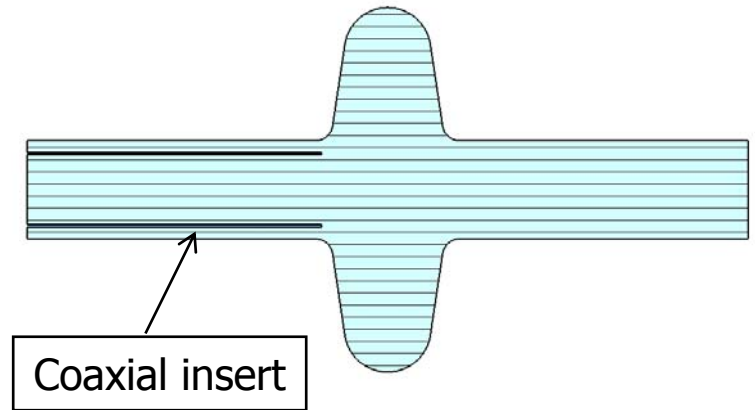
Studies on
— Muti-cell cavity structure
— Damping of the unwanted dipole
— LOM and HOM damping schemes
— RF couplers
— Multipactings

Coaxial insert

Q_{ext}

R=33mm
R=34mm
R=32mm

Coaxial insert length (mm)

3-Cell Cavity with damping

Coaxial insert to damp LOM, but not unwanted dipole mode

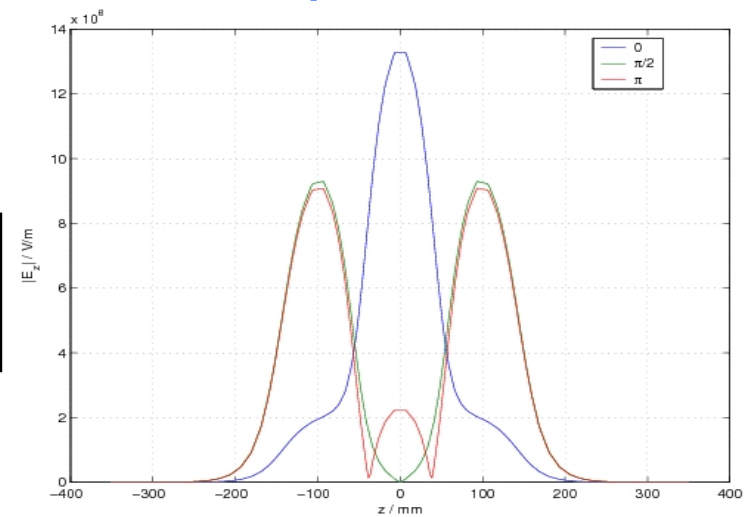| Mode	Frequency / GHz	Q_{ext}
0	1.0344	4.7E4
π/2	1.0503	1491
π	1.0508	1539
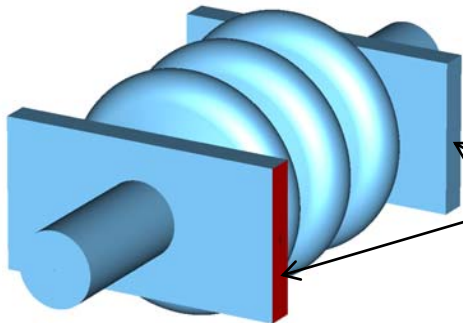
Waveguides to damp LOM, HOM and unwanted dipole mode

- Monopole 0 mode is trapped due to cavity symmetry
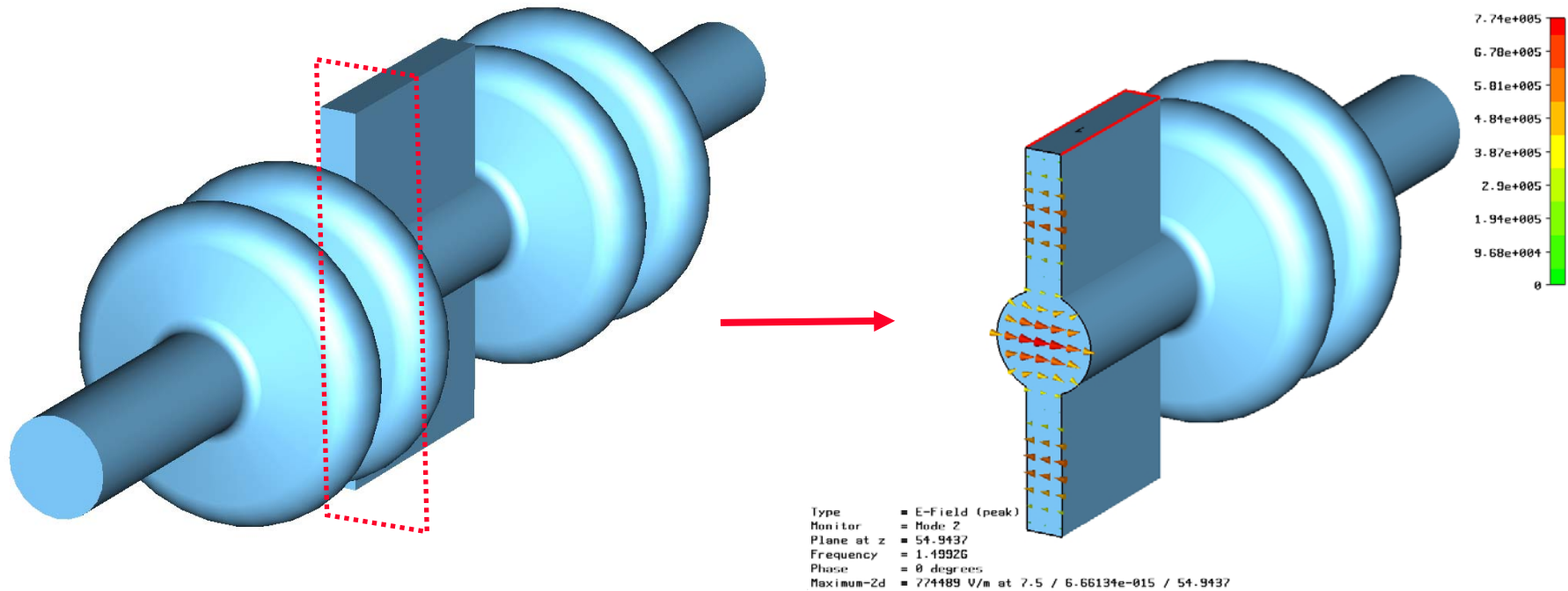- Difficult to be damped either by coaxial insert or waveguides
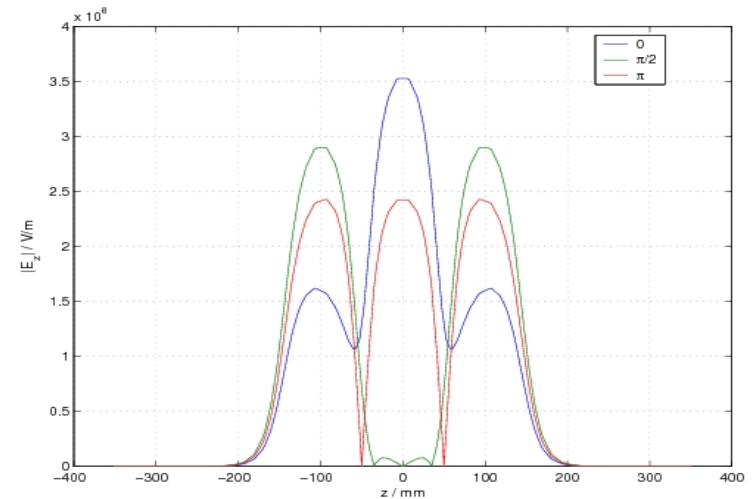
Dipole modes

Monopole modes

Type   = E-Field (peak)
Monitor   = Mode 2
Plane at z   = 54.9437
Frequency   = 1.4992G
Phase   = 0 degrees
Maximum-2d   = 774489 V/m at 7.5 / 6.66134e-015 / 54.9437

Two 2-cell cavity with waveguide in between beam pipe to damp unwanted dipole mode

Unwanted dipole mode

- Damping TE_{11} mode in beam pipe
- Effective in damping unwanted dipole mode
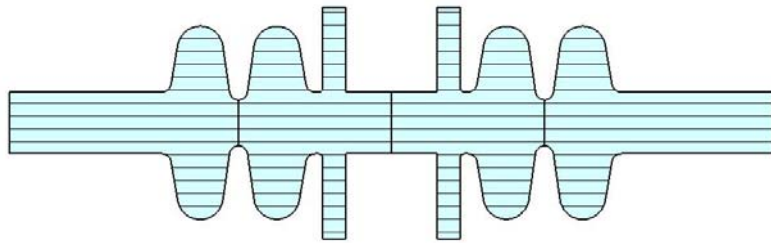- The waveguide does not couple strongly with the LOMs

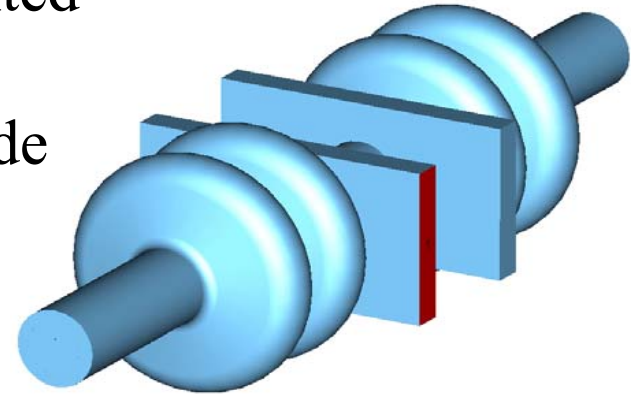| Mode	Frequency / GHz	Q_{ext}
π	1.5022	1774
0	1.5121	1470

2-Cell Super-Structure with damping: B

Waveguide near beam iris to damp unwanted
dipole mode (TM) directly
- Strong damping on unwanted dipole mode
- Modest damping to LOM, 0 mode

The wavgude also couples with
the deflecting mode (TE20), cut-off
Frequency ~ 1.8-GHz $\rightarrow$ longer WG

Monopole modes

Mode	Frequency / GHz	Q_{ext}
0	1.0505	7330
π	1.0554	1730

Unwanted dipole modes

Mode	Frequency / GHz	Q_{ext}
π	1.5012	1059
0	1.5112	706

2-Cell Super-Structure with hybrid damping

Both waveguide and coaxial insert are used, but at different ends

- Coaxial insert does not need to go too much into the cavity
- Both the unwanted dipole mode LOM monopole mode are damped effectively
- Couplers may give extra damping
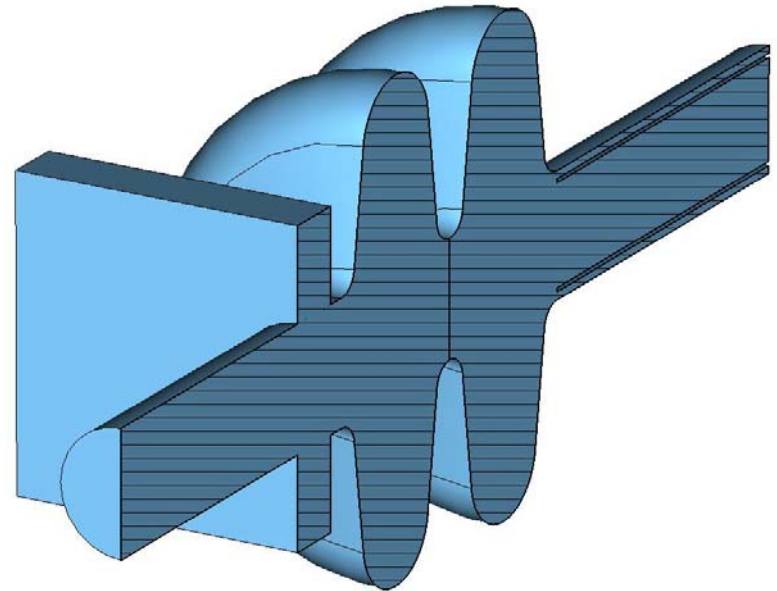
Unwanted dipole modes

Mode	Frequency / GHz	Q_{ext}
π	1.5012	1059
0	1.5112	706

Monopole modes

Mode	Frequency / GHz	Q_{ext}
0	1.0693	1157
π	1.0829	1892

2-Cell Super-Structure with WG damping + couplers

- Two waveguides to dam both LOM monopole modes and unwanted dipole and HOM modes
- The deflecting mode couples to the waveguide as well in TE_{20} mode; cutoff frequency of the TE_{20} ~ 1.8 GHz
- RF couplers on beam pipe, not being simulated yet

= Vacuum
= Normal
= 1
= 1
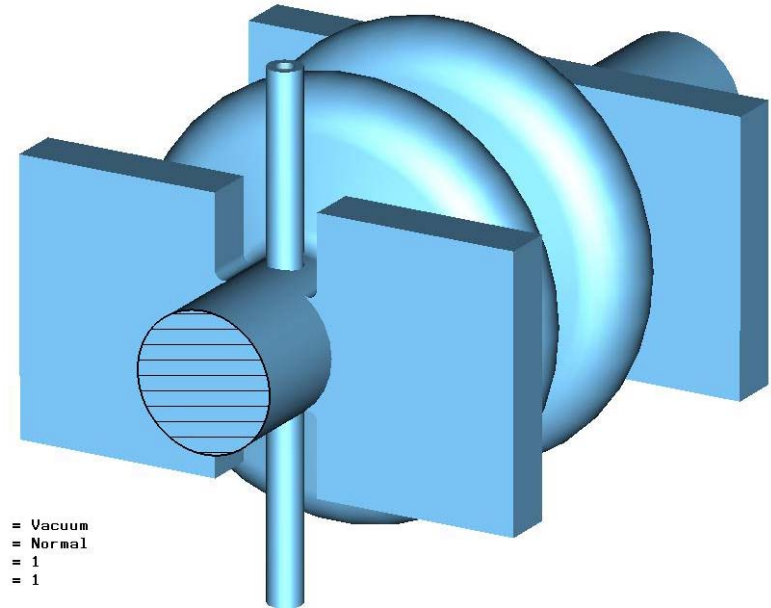
Unwanted dipole modes

Mode	Frequency / GHz	Q_{ext}
π	1.5016	1020
0	1.5240	526

Monopole modes

Mode	Frequency / GHz	Q_{ext}
0	1.0633	1694
π	1.0711	1762

Summary

- **Explore options for damping LOM, HOM and unwanted dipole modes in multi-cell cavity**

- **3-cell cavity has trapped LOM mode and hard to damp**

- **2-Cell super-structure is promising:**

  — **Hybrid damping scheme**
    - **Q_{LOM} ~ 1000 or less**
    - **$Q_{UW-Dipole}$ ~ 1000**

  — **Waveguides damping scheme**
    - **Q_{LOM} ~ less than 2000**
    - **$Q_{UW-Dipole}$ ~ 1000**

  — **Waveguide damping on beam pipe**
    - **$Q_{UW-Dipole}$ ~ less than 2000, but not efficient for damping LOM**

- **Coupler may help to damp HOM modes, will be studied soon**

- **Depending on applications, some of the designs may already give satisfactory performance, but need to be further studied**